Puzzle: Our image of the world is detected by photoreceptors, lying at the bottom of the retina. Lateral neural layers, for processing the image temporally, spectrally, and spatially, come in front the photoreceptors, not behind them. These neural layers and their nuclei are scattering and aberrating the images. This reverse order of the retina is a long-standing puzzle, which we wish to explain by theory and experiment.

It turns out that Müller cells have a higher refractive index (Franze et al. PNAS 2007) so we built a computer model to simulate their optical effect.

Müller transmission and cone pigments:
Cones are colour sensitive, mostly to blue, green and red light. Colour-blind rods are ×100 more sensitive, and cover 95% of the retina (outside the small central fovea). So for daytime vision we need more light into cones, and preferably green-orange.

To our surprise, the spectra of the cones’ pigments matched the colours transmitted by the Müller cells, according to our calculations for the human eye. Light is concentrated into the green and red cones by a factor of 8, into blue cones by a factor of four, and rods lose 15% of the light by the colour differentiation.

Experimental validation: We used retinas of guinea pigs to see if indeed light is differentiated by it. We modified a confocal microscope and added a white light source to it to see how it propagates through the retina. Indeed we found the expected light concentration according to colours.

Results:
Simulations and measurements match well for most colours except for the blue (d).
We also showed that Müller cells indeed lead the light into cones alone.

Summary:
Müller cells improve day-time vision without hampering night-time vision. There is a benefit in an inverted retina.

More details:
3. A. M. Labin and E. N. Ribak, “color sorting by retinal waveguides”. Optics Express, Accepted (2014)